

Remote Sensing Of Vegetation Stress as an Indicator of Subsurface Soil Instability

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Abstract

Soil instability beneath the surface can lead to catastrophic infrastructure failures and environmental hazards. Early detection of such subsurface instabilities is crucial for effective risk mitigation. Vegetation stress, observable via remote sensing, has emerged as a promising proxy for detecting areas affected by subsurface soil anomalies such as sinkholes, subsidence, or soil liquefaction. This paper reviews the principles and applications of remote sensing technologies, especially multispectral and hyperspectral imaging, in monitoring vegetation stress related to underlying soil instability. Vegetation indices like NDVI (Normalized Difference Vegetation Index) and stress-related spectral signatures are discussed. A table summarizing common vegetation indices used in soil instability detection is included. Case studies highlight successful monitoring in mining and karst regions. Limitations such as atmospheric interference and seasonal variations are addressed. The study concludes that remote sensing of vegetation stress offers a non-invasive, cost-effective approach for preliminary

screening of subsurface soil instability zones, aiding geotechnical investigations and infrastructure planning.

Keywords: *Vegetation Stress, Remote Sensing, Soil Instability, NDVI, Hyperspectral Imaging, Subsurface Monitoring*

INTRODUCTION

Subsurface soil instability poses significant threats to construction, agriculture, and natural ecosystems. Traditional detection methods like borehole drilling and geotechnical surveys are invasive and costly. Vegetation growing above unstable soil often exhibits stress responses due to altered moisture availability, nutrient deficiency, or soil compaction. Remote sensing techniques allow for detecting such vegetation anomalies over large areas with temporal frequency, offering an efficient tool for early warning and mapping of soil instability zones.

This paper explores how remote sensing-derived vegetation stress indicators can serve as proxies for subsurface soil instability. The focus lies on spectral indices, imaging techniques, challenges, and practical applications.

REMOTE SENSING TECHNIQUES FOR VEGETATION STRESS DETECTION

Remote sensing platforms such as satellites, UAVs, and airborne sensors capture reflected radiation from vegetation at various wavelengths. Healthy vegetation strongly absorbs visible light but reflects near-infrared (NIR), while stressed vegetation shows altered reflectance patterns.

- **Multispectral Imaging:** Captures data in discrete spectral bands including visible and NIR. It enables calculation of vegetation indices like NDVI, which quantify vegetation health.
- **Hyperspectral Imaging:** Provides continuous spectral data across hundreds of narrow bands, allowing for detailed biochemical and physiological analysis of vegetation stress.
- **Thermal Imaging:** Measures canopy temperature, which increases during water stress, complementing spectral data.

VEGETATION INDICES USED FOR SOIL INSTABILITY DETECTION

Index	Formula	Purpose	Application
NDVI	$(\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})$	General vegetation health	Detects areas of vegetation decline due to soil issues
SAVI (Soil Adjusted Vegetation Index)	$((\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red} + L)) * (1 + L)$, $L=0.5$	Minimizes soil brightness effects	Useful in sparse vegetation regions
PRI (Photochemical Reflectance Index)	$(R_{531} - R_{570}) / (R_{531} + R_{570})$	Indicates photosynthetic activity	Sensitive to plant stress due to water or nutrient shortage
NDWI (Normalized Difference Water Index)	$(\text{NIR} - \text{SWIR}) / (\text{NIR} + \text{SWIR})$	Monitors vegetation water content	Assesses drought stress linked to soil moisture deficits

Table 1: Common Vegetation Indices Relevant to Soil Instability Monitoring

MECHANISMS LINKING VEGETATION STRESS TO SUBSURFACE SOIL INSTABILITY

Soil instability phenomena such as subsidence, sinkholes, and liquefaction disrupt soil structure and water retention, leading to:

- **Reduced Root Zone Moisture:** Affects plant hydration, visible as reduced NDVI or increased thermal signatures.
- **Soil Compaction and Nutrient Depletion:** Limits root growth and nutrient uptake.
- **Surface Deformation:** Causes mechanical damage to root systems.

These stressors manifest as spectral changes detectable by remote sensors.

CASE STUDIES

1. Mining-Induced Subsidence, Jharkhand, India

Multi-temporal Landsat and Sentinel-2 data revealed progressive decline in NDVI over abandoned mining sites prone to ground collapse. Vegetation stress patterns corresponded spatially to known subsidence areas validated by ground surveys.

2. Karst Terrain in Guangxi, China

Hyperspectral imaging detected spectral shifts in vegetation on limestone regions with underground cavities. Early vegetation stress indicators preceded visible surface deformation, providing critical early warnings.

TABLE 2: Vegetation Stress and Soil Instability Correlation from Case Studies

Location	Soil Instability Type	Vegetation Index Change (%)	Detection Lead Time
Jharkhand Mining Area	Subsidence	NDVI decrease ~20%	6 months
Guangxi Karst Region	Sinkholes	PRI decrease ~15%	3 months

Table 2: Vegetation Stress Indicators as Precursors to Soil Instability

CHALLENGES AND LIMITATIONS

- **Atmospheric Effects:** Clouds, haze, and aerosols interfere with reflectance measurements.
- **Seasonal Variability:** Vegetation phenology affects spectral signals, complicating anomaly detection.
- **Mixed Pixels:** Coarse resolution sensors may include multiple land covers, reducing accuracy.
- **Calibration Needs:** Ground truth data is essential to validate remote sensing interpretations.

FUTURE PROSPECTS

Emerging techniques such as integration of remote sensing data with soil moisture sensors and machine learning models promise enhanced detection capabilities. UAV-based hyperspectral

platforms can provide ultra-high spatial and spectral resolution data. Synergistic use of multi-source data will improve predictive mapping of subsurface instability.

CONCLUSION

Remote sensing of vegetation stress offers a non-destructive, scalable approach to identify subsurface soil instability zones. Vegetation indices like NDVI and PRI, derived from multispectral and hyperspectral data, have demonstrated effectiveness in detecting early warning signs associated with soil deformation and subsidence. Despite challenges related to atmospheric conditions and phenological cycles, advancements in sensor technology and data analytics continue to improve reliability. Integrating vegetation stress monitoring with conventional geotechnical methods can significantly enhance risk assessment and infrastructure safety.

REFERENCES

- [1] Jones, H.G., "Remote Sensing of Vegetation Stress," *Progress in Physical Geography*, vol. 37, no. 4, pp. 573-593, 2013.
- [2] Smith, A.B., and Lee, C., "Hyperspectral Monitoring of Soil Subsidence Using Vegetation Indices," *Remote Sensing*, vol. 11, no. 3, pp. 293-308, 2019.
- [3] Patel, S., et al., "Detecting Mining-Induced Subsidence Using Satellite-Based NDVI Changes," *International Journal of Applied Earth Observation and Geoinformation*, vol. 85, pp. 101970, 2020.
- [4] Chen, X., et al., "Vegetation Stress Detection in Karst Areas Using Hyperspectral Data," *Environmental Monitoring and Assessment*, vol. 192, no. 6, pp. 376, 2020.
- [5] Zhu, Z., and Woodcock, C.E., "Object-Based Cloud and Cloud Shadow Detection in Landsat Imagery," *Remote Sensing of Environment*, vol. 118, pp. 83-94, 2012.
- [6] Turner, D., et al., "Soil Moisture and Vegetation Interactions: Remote Sensing Perspectives," *Advances in Water Resources*, vol. 138, 103567, 2020.
- [7] Singh, V.P., and Mukherjee, D., "Integration of Remote Sensing and Geotechnical Surveys for Subsidence Detection," *Engineering Geology*, vol. 267, pp. 105523, 2020.
- [8] Dasgupta, S., et al., "Machine Learning Approaches for Soil Instability Mapping Using

Vegetation Data,” *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 14, pp. 5884-5897, 2021.